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LF/MF receivers with synchronous demodulation for double- or single-sideband transmissions

No. 1970/29

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

LF/MF RECEIVERS WITH SYNCHRONOUS DEMODULATION FOR DOUBLE- OR SINGLE-SIDEBAND TRANSMISSIONS

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(RA-66)

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Summary

The theoretical and practical requirements for introducing synchronous demodulation into domestic radio receivers for m.f./l.f. broadcasting are discussed. The difficulties encountered in the construction and operation of experimental receivers with an optional synchronous mode of demodulation are outlined. Subjective tests were carried out with these receivers, both in the home and in the laboratory, to assess the advantages of synchronous demodulation under selective-fading conditions. The results show some improvement under these conditions but good reception is still limited by factors other than non-linear distortion.

1. Introduction

Congestion in medium- and long-wave sound broadcasting is becoming worse, and there are recurrent proposals to make available more channels by moving towards some form of single-sideband (s.s.b.) transmissions with a substantially reduced carrier-frequency spacing. To obtain a positive advantage from such a change the listener will require a new receiver, for at least one or two principal reasons. Firstly, whatever the modulation system chosen, a receiver with a higher degree of selectivity than those currently available will be required if the channel separation is reduced. The production of receivers with high overall selectivity, at little more than existing costs, may not prove difficult in view of the recent advances in the development of mechanical filters, integrated circuits etc. Secondly, except for the compatible single-sideband system, which has serious disadvantages, a special demodulator is required in the receiver to avoid non-linear distortion.

These special demodulators would be much more complicated than the conventional envelope detector and could be based either on non-synchronous methods,[1,2] where a correction signal is applied to the output of an envelope detector to cancel the harmonic distortion components, or on the well-known synchronous methods involving regeneration or synthesis of the carrier. Full implementation of the synchronous approach is attractive because it offers the added bonus of eliminating non-linear distortion even when the received signal is subject to severe frequency-selective fading.

The question is: can a stable form of synchronous demodulator be introduced into a domestic-type radio which would be acceptable, economically and otherwise? Furthermore, if it can, how much of an advantage is it for entertainment-type broadcasting under fading conditions of reception? The answers to these questions are important in relation to general policies for the future of the m.f./l.f. broadcasting bands; it has already been proposed[3] that they should be developed extensively for sky-wave coverage at m.f.

An attempt was made in this investigation to modify two portable radio sets to include synchronous demodulation, and to assess their performance and limitations.

2. Theoretical requirements

The theory of synchronous demodulation is conceptually simple; the r.f. signal is multiplied by a periodic signal synchronised with the carrier and the product is passed through a suitable base-band filter to remove r.f. components. In spectral terms, the process amounts to pure frequency translation of the r.f. signal spectrum down to base-band, so that the original component frequencies of the modulating signal are restored. The synchronous method will, in theory, correctly demodulate amplitude-modulated signals with any degree of sideband asymmetry or carrier suppression, in the sense that the recovered signal is free from non-linear distortion. It will *not* alleviate linear distortion (i.e. the accentuation of some audio frequencies and the attenuation of others) arising from multipath propagation.

For sound broadcasting, it is found[4] that when a s.s.b. transmission is demodulated the locally-generated carrier-wave used for the demodulator need only be within a few Hertz of the frequency of the received carrier, and its relative phase is clearly unimportant. On the other hand, for vestigial sideband (v.s.b.) or double-sideband (d.s.b.) input signals the frequencies of the demodulating and received carriers must be identical, otherwise disturbing cyclic beats of sound intensity are produced. Providing that frequency identity can be maintained, the amplitude of the signal output (but not the noise output) will vary in proportion to $\cos\phi$, where ϕ is the phase difference between the locally-generated carrier and the received carrier. The phase is not therefore very critical, although it should remain reasonably close to the ideal in order to maintain a good signal-to-noise ratio.

In theory, therefore, the synchronising requirements for the demodulating carrier are substantially less stringent if the receiver has to deal only with s.s.b. transmissions. This fact has led to recent suggestions[3,5] for the m.f. receiver of the future to be based mainly on deriving the demodulating carrier by local frequency-synthesis, in conjunction with a precise, integrally-related structure of channel frequencies and with s.s.b. modulation.

The more stringent synchronising requirement when the demodulator has to deal with d.s.b./v.s.b. signals can be eased by sending synchronising information, either as a reasonably strong carrier or as a pilot tone. This leads to many ways of implementing synchronous demodulation based on automatic frequency-locking techniques, some of which are discussed below.

3. Methods of synchronous demodulation

The various approaches to the technique of synchronous demodulation can be grouped, according to the manner by which the demodulating carrier is generated, into three principal classes:

(a) Frequency synthesis of the demodulating carrier. Here the frequency required is built-up from that of a highly stable basic oscillator. The carrier frequency must be known *a priori*. This method is often employed in professional communication equipment for the reception of suppressed-carrier single-sideband transmissions. The cost of a sufficiently stable oscillator, and its associated circuitry, precludes the the method for a general, domestic radio receiver in the immediate future and it will not be considered further in this report.

(b) Locked oscillator. This requires an oscillator controlled in frequency and phase by information extracted from the received signal, often by effectively isolating the carrier component but sometimes by using the information in the sidebands.[6] This approach leads to a number of circuit arrangements of varying degrees of complexity, some of which are sufficiently promising to be worth investigating for use in domestic radio receivers.

(c) Receiver-carrier isolation. The filtered carrier component may be amplified and used directly for demodulation. Use is made of a narrow-band filter at a suitable intermediate frequency, together with an automatic means of ensuring that the received signal is tuned so as to maintain the intermediate carrier near the centre of the passband. This is an attractive method for use in domestic receivers, although a piezo-electric element may be required for the filter. Clearly, the method is inapplicable to suppressed-carrier transmissions.

Having obtained a synchronised local carrier by one of the above methods, the remainder of the demodulation process consists of multiplying the r.f. signal by the synchronised carrier. This is normally carried out by using the latter to drive an r.f. switch, the sampled signal being then followed by a low-pass filter to give a low-level a.f. output. Alternatively, integrated-circuit multipliers can be used to form the product.

4. Experimental receiver

4.1. Practical requirements

On the assumption that the greatest demand for m.f. broadcast receivers will continue to be for battery-operated transistor portables, any new type of receiver must be adaptable to this format. It is also highly desirable that the features of current a.m. receivers which account for their popularity, such as convenient size and portability, ease of tuning, low power consumption, low cost etc., be retained as far as possible. To this end, the experiments reported here consisted of modifying two commercial transistor portables by incorporating small synchronous demodulator units within their existing cases, and including a switch to select either the existing 'envelope' mode of demodulation or the new 'synchronous' mode. Although some advantages would be obtained by designing a receiver *ab initio* with synchronous demodulation in mind it was felt that, for the purposes in view, an attachment with the minimum of circuit change would be an expedient but sufficiently realistic exercise. The objective, therefore, was not to produce a new design of receiver of commercial viability but, rather, to explore the possibility of introducing a simple form of synchronous demodulation and to assess the practical advantages and limitations in relation to entertainment broadcasting at m.f.

4.2. Initial trials

The first attempt at fitting a conventional transistor portable with a synchronous demodulator was based on the locked-oscillator approach (i.e. method (b) in Section 3). Fig. 1 shows the general outline of one scheme which was investigated experimentally. Briefly, a voltage controlled oscillator (v.c.o.) working at a nominal frequency of four times the intermediate frequency (i.e. at 4 x 470 kHz) provides the source of the demodulating carrier. A frequency-dividing circuit provides two outputs at the intermediate frequency which are always in precise quadrature. An integrated circuit multiplier is used to form the product of one of the divider outputs and the modulated i.f. signal; the result, after filtering, provides the required feed to the a.f. amplifier.

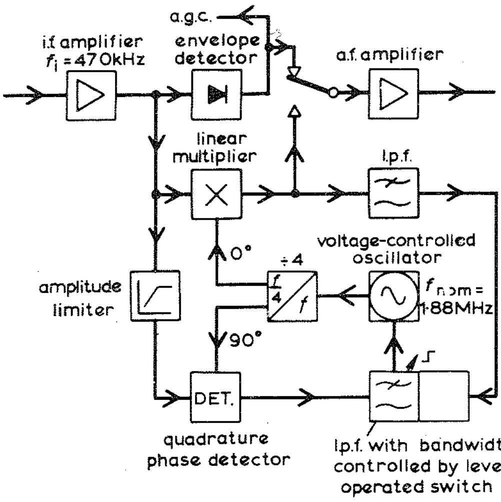

a.g.c.
i.f. amplifier f_i = 470kHz
envelope detector
a.f. amplifier
linear multiplier
l.p.f.
0°
÷4
voltage-controlled oscillator
f_{nom} = 1·88MHz
amplitude limiter
$\frac{f}{4}$
f
90°
DET.
quadrature phase detector
l.p.f. with bandwidth controlled by level-operated switch

Fig. 1 - Synchronous demodulator arrangement using locked oscillator for carrier generation

Frequency/phase control of the demodulating carrier is obtained by comparing the other (quadrature) output from the divider with an amplitude-limited version of the i.f. signal in a quadrature phase detector. The d.c. output of the detector varies with the mean phase difference between the inputs and it forms the control signal for the v.c.o. Ideally, this control signal should be derived from the incoming carrier only and not be perturbed by the modulation sideband components when optimum frequency-locking has been obtained. To achieve this, it is necessary to have an extremely narrow-bandwidth low-pass filter following the phase detector so that the output is substantially d.c. The smaller the bandwidth, however, the smaller is the 'capture' range of the control circuit and the greater is the difficulty of initial manual tuning. In an attempt to overcome this problem, the RC low-pass filter in the control loop was constructed with means of altering its effective bandwidth. An extra capacitance was switched-in electronically, being triggered by the d.c. component of the domodulated signal. Thus, when the system is locked a d.c. component appears at the output of multiplier and this, via the electronic switch, cuts the bandwidth of the control-loop filter, in effect making the locking more rigid. Under off-tune conditions the control-loop bandwidth is an order of magnitude greater, thus permitting a reasonable capture range.

The above demodulator arrangement was, however, abandoned because it was found that the following difficulties could not be satisfactorily overcome:

(a) instability of the first local oscillator driving the r.f./i.f. conversion stage of the receiver and, to a lesser extent, the instability of the v.c.o. in the demodulator;

(b) spurious locking of the v.c.o.

(c) adventitious coupling between the i.f. signal stages and the v.c.o., which tended to pull the phase of the oscillator in synchronism with the modulation;

(d) harmonics of the v.c.o. and divider stages coupling into the r.f. circuits, giving high-order mixing and filling the band with whistles.

Generally, the principle problems were centred around the need for exceptionally good screening and isolation of the v.c.o. circuits, bearing in mind the confined environment of a small portable receiver.

4.3. Final arrangement

Greater success was obtained using the arrangement shown in Fig. 2, which follows closely a method of carrier isolation proposed by Stumpers, Hurck and Voorman.[7] In this scheme, the intermediate carrier component is isolated from the modulation sideband components by a series-resonant quartz-crystal filter, whose passband is centred at the nominal intermediate frequency (470 kHz). The filter has a bandwidth of ±8 Hz approximately. When the carrier is at the centre of the passband, there is no phase-shift between the output and the input to the filter so that the isolated carrier, which is directly applied as the second input to an integrated-circuit multiplier to perform the demodulation, is then in perfect synchronism. At other positions of the carrier within the filter passband, there is a corresponding phase shift of the isolated carrier (see inset diagram in Fig. 2) with respect to the input. This phase shift is detected using a quadrature phase detector as shown in Fig. 2, and provides an error signal for the automatic frequency control of the intermediate carrier via the local oscillator of the receiver. The output of the phase detector is filtered to attenuate frequencies above about 1 Hz, and this (virtually) d.c. signal is then applied to a varactor diode across the existing local oscillator coil of the receiver.

In order to provide constant-amplitude inputs to the phase detector, high-gain (>40 dB) limiters are necessary, particularly for the isolated carrier whose amplitude at the crystal filter output varies over a wide range during the initial automatic pull-in period.

The basic arrangement described above was used for the synchronous demodulator units incorporated in two medium-priced portable receivers. The demodulator circuits differed in detail between the two receivers in order to effect optimum matching to the original receiver circuits.

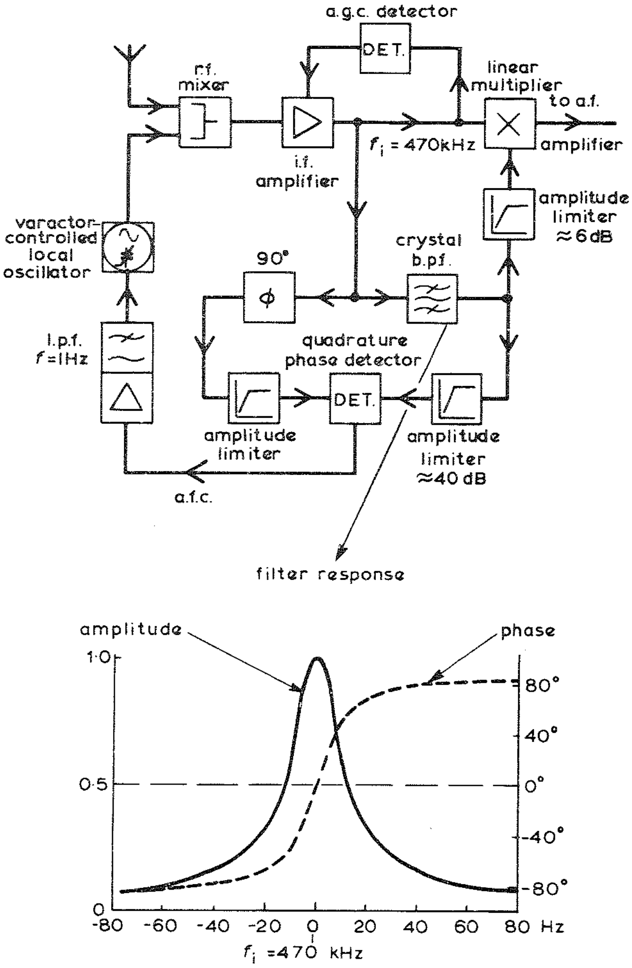


Fig. 2 - Final arrangement used for experimental synchronous demodulator
(Inset: response of crystal filter for intermediate carrier isolation)

One of the receivers, which was of recent design, used a single integrated circuit for r.f., i.f. and low-level audio amplification. Moreover, its i.f. selectivity was obtained by a pair of tuned circuits coupled by a single, ceramic resonant element. The two principal problems in fitting the synchronous demodulator unit of this particular receiver were the stability of the power supply and the derivation of automatic gain control. Significant variations of the power supply were found when strong low-frequency (≏100 Hz) audio components were present; owing to inadequate decoupling these tended to pull the local oscillator frequency and led to distortion at these frequencies. To overcome this effect, it was found essential to stabilise the supply voltage to the synchronous demodulator unit and to use a slow-acting a.f.c. control circuit. Other difficulties that had to be overcome arose from the low-level of the i.f. output in this receiver, and from a small amount of local oscillator break-through.

For both synchronous demodulator units, integrated circuits were used as far as possible and particular attention was given to the need for minimising the additional current drain and cost of the units, especially for the one incorporated in the more modern receiver. Even so, to ensure adequate performance, the overall current drain was found to be approximately 50% greater, when using the synchronous demodulator, than in the normal (envelope-detecting) mode of operation. It was estimated that the extra components necessary for implementing this form of synchronous demodulation would have doubled the cost of the more modern receiver. These increases could, however, be reduced somewhat with further circuit developments, especially if the receiver was designed as a whole with synchronous demodulation in mind.

As a potentially cheaper alternative to a quartz-crystal filter for isolating the carrier, a digital (switching-type) filter was investigated. This means was abandoned after initial tests, however, because harmonics of the switching pulses were unaviodably picked-up by the ferrite-rod aerial, filling the band with unpleasant whistles.

In both receivers, an attempt was made to equalise the overall frequency responses when switched between the envelope and synchronous modes of demodulation. Even so, differences in spectral response and, also, in residual non-linear distortion were still perceptible.

To illustrate the detailed circuitry involved in the synchronous demodulator units, Fig. 3 shows the circuit applied to the more conventional of the two portable receivers.

5. Receiver performance

5.1. Objective measurements

Development of the synchronous demodulators was curtailed at a stage where the receivers performed sufficiently well to carry out comparative subjective assessments of the two modes of demodulation under typical fading-signal conditions. A summary of several objective measurements on the receivers at this stage is given in Tables 1, 2 and 3. These results were obtained using a.m. signals fed directly into the aerial sockets of the receivers from signal generators and low-power modulators. The latter, which have been described elsewhere,[8] had provision for generating either normal a.m. (double sideband) or single-sideband r.f. signals, and with the facility to suppress or enhance the strength of the carrier component as required.

TABLE 1

Total Harmonic Distortion with Single-tone Modulation

Modulation Depth %	Modulating Tone Frequency	Transmission System	Receiver	DISTORTION FACTOR, %	
				Envelope Demodulator	Synchronous Demodulator
80	300 Hz	D.S.B.	A	6	2·5
			B	2	9
		S.S.B.	A	11	7·5
			B	20	5
	1000 Hz	D.S.B.	A	8·5	4·5
			B	1	9
		S.S.B.	A	10	4·0
			B	16·5	5
200	1000 Hz	D.S.B.	A	35	7·5
			B	45	4

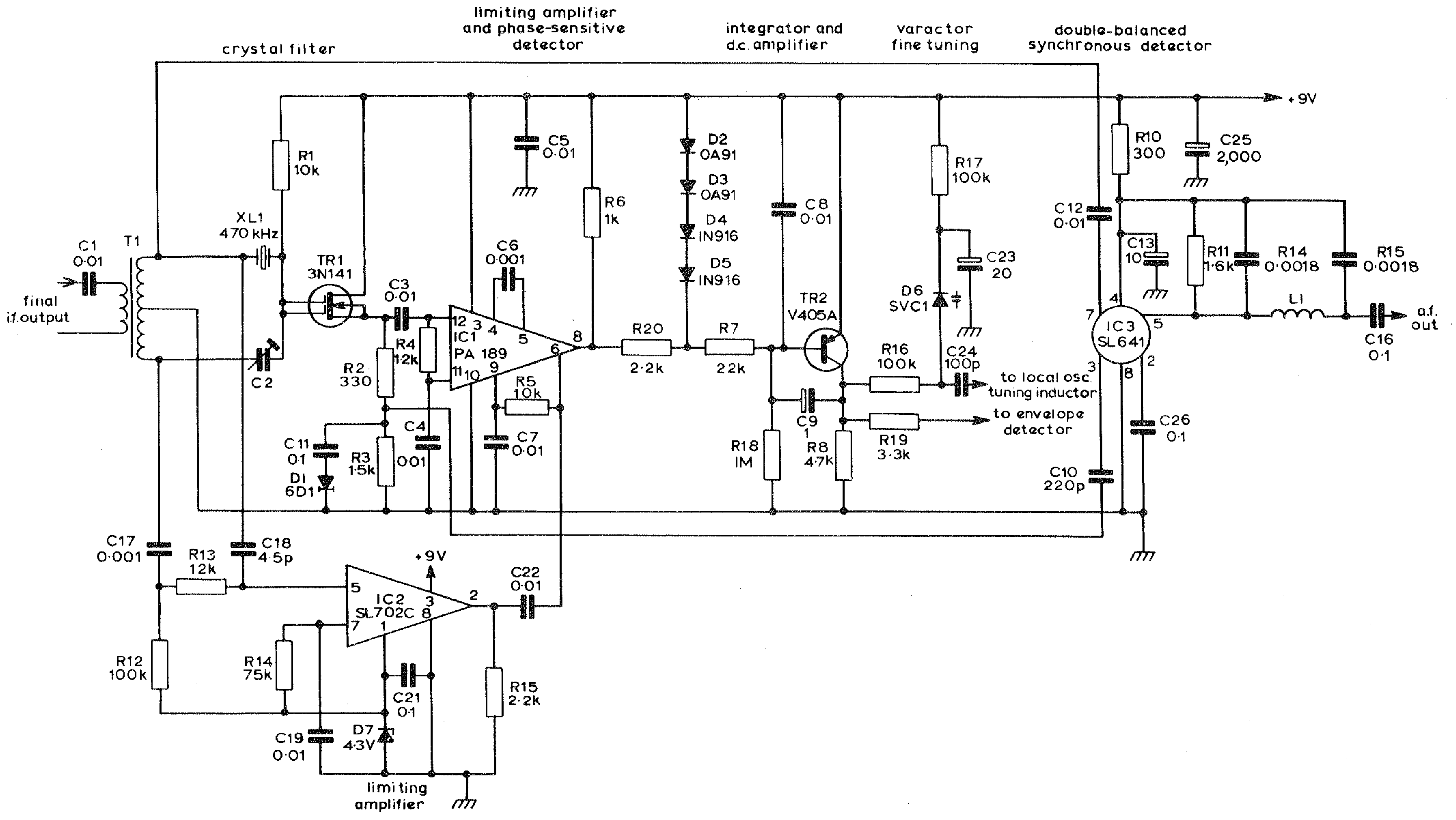


Fig. 3 - Demodulator circuit used for an experimental receiver

TABLE 2

Carrier Thresholds in the Synchronous Mode: Single-tone (1000 Hz) Modulation

Criterion	Receiver	Carrier Threshold: dB rel. to carrier at 100% modulation	
		D.S.B.	S.S.B.
Significant increase in non-linear distortion	A	−12	−10
	B	−18	−12
Locks to sideband component	A	−30	−10
	B	−32	−18

TABLE 3

Tuning Characteristics in the Synchronous Mode

Receiver	Hold-in Range kHz	Capture Range kHz
A	±5	±4
B	±7	±2·5

All the measurements were made with a carrier frequency of 1·1 MHz, approximately, using either a 300 Hz or a 1000 Hz audio tone as a modulating signal.

Receiver A refers to the transistor portable of more conventional circuit design, while B is a more recent model from a different manufacturer using integrated circuitry, as mentioned earlier. The laboratory subjective tests described in a later section were carried out using receiver B only.

The measurements shown in Table 1 are the overall distortion factors for the receivers and refer to the audio waveform at the speech coil of the loudspeaker. It will be noted that, in the normal envelope mode of demodulation, receiver B has an exceptionally low (non-linear) distortion factor for this class of receiver. This is believed to be due to the use of an 'infinite impedance' type of envelope detector (part of the integrated circuit) rather than the usual diode arrangement.

Table 2 refers to the synchronous mode of demodulation, and it indicates the minimum strength of the carrier, relative to that of the side-frequency component(s), required to maintain stable operation of the synchronous demodulator. Starting with a full carrier transmission (100% modulation), and with the demodulator firmly locked to the carrier, the carrier was then slowly suppressed until the a.f.c. control failed and then re-locked on to an adjacent side-frequency. This threshold occurred at a higher level of carrier for the s.s.b. transmissions because of the stronger side-frequency component and the associated carrier-phase perturbation. Under frequency-selective fading conditions where strong carrier fades are likely, the results show that there is a danger of sudden demodulator failure when the interfering (sky-wave) signal field strength is greater than 90% of the wanted signal field strength for d.s.b. transmission and 80% for s.s.b. transmissions (receiver B). Whether or not the demodulator will actually jump out of lock during such fades with normal programme modulation will depend on the simultaneous strength of the adjacent sideband components. The objective tests using 1000 Hz, single-tone modulation indicated that when the demodulator had re-locked to a side-frequency component it was necessary, in the absence of a momentary pause in the modulation, to increase the carrier to almost its full level before correct locking was again restored in the case of d.s.b. and to a somewhat greater level for s.s.b.

The measured 'hold-in' and 'capture' ranges shown in Table 3 refer to a carrier frequency of 1·1 MHz with d.s.b. modulation. The tuning characteristics of the receivers in the synchronous mode depended on the carrier frequency and varied significantly over the tuning range of the m.f. band. This results from the variation in the voltage versus frequency characteristics of the varactor-controlled local oscillator over the tuning range. One solution to this problem would be to use variable-permeability inductance instead of capacitance tuning.

Receiver B had the slowest 'pull-in' characteristic but, once in lock, had the more stable 'hold-in' performance of the two receivers.

5.2. Subjective assessments in the home

A total of ten engineers carried out night-time listening tests in their homes using the converted receivers. They were asked to assess the grade of reception for each mode of demodulation while listening to normal a.m. broadcast transmissions in the m.f. range. The participants (5 for each receiver) made assessments both for steady, non-fading transmissions of their choice and for any obviously fading transmissions which they were able to locate. In addition, comments were invited on the general performance and tuning characteristics of the receivers. Absolute assessments were made using the following (EBU) six-point scale:

Score	Grade of Reception
1	Excellent
2	Good
3	Fairly good
4	Rather poor
5	Poor
6	Very poor

The factors contributing to the general assessments of reception quality included instrumental degradations such as frequency response, residual non-linear distortion, tuning stability etc. as well as the deleterious effects of interference, noise and additional distortion due to channel congestion and propagation phenomena.

TABLE 4

Mean Scores for Home-Listening Tests
(1 = excellent, 6 = very poor)

Receiver	NON-FADING STATIONS		FADING STATIONS	
	envelope	synchronous	envelope	synchronous
A	2·6	3	3·9	4
B	3	2·8	4·1	3·4

The mean scores (average for all listeners and all stations assessed) obtained from these brief home-listening tests are shown in Table 4. It will be seen that, for receiver A, envelope demodulation was preferred for non-fading stations, while no significant difference was found with fading transmissions. From the accompanying comments, the lack of improvement with synchronous demodulation seen in this latter result appears to be due to the sudden failure of the a.f.c. during deep fades; it then takes some time for the tuning to revert to a stable condition. This threshold effect, if it occurs, tends to offset any improvement in non-linear distortion up to the failure point. For receiver B, on the other hand, a significant improvement in the overall grade of reception was found with synchronous demodulation for fading stations. (As mentioned previously, receiver B operating in the synchronous mode has the better hold-in and a.f.c. threshold characteristics.) The stations for which a definite improvement in reception with synchronous demodulation was recorded were in the distance range 300 – 600 km and reception was predominantly via the sky-wave.

The principal general comments on the receivers operating in the synchronous mode were:—

(a) Station selection is generally tedious and rather irritating.

(b) The noisy side-whistles during manual tuning are unpleasant.

(c) Tuning is difficult with weak signals, especially in the presence of strong adjacent-channel transmissions.

(d) Performance during cyclic deep fades is unpredictable.

5.3. Subjective assessments in the laboratory

A series of subjective tests were carried out using simulated fading signals generated in the laboratory. The principal prupose was to investigate in greater detail, and under controlled conditions, the relative performance of the two modes of demodulation which could be expected near the night-time limit of the primary (ground-wave) service of a m.f. transmitter. Also, the performance with single-sideband plus carrier transmissions could be assessed.

Only receiver B was used for the laboratory tests, because the initial home-listening tests showed this receiver to have a positive advantage for the reception of fading signals in the synchronous mode.

5.3.1. Test arrangement

Fig. 4 shows the arrangement used to generate the required signals, simulating fading conditions etc., for assessing the receiver performance. The test programme consisted of recorded passages of male speech, solo concert piano and orchestral music. The modulation bandwidth was restricted to 4·5 kHz and the audio signal compressed ($\simeq$10 dB) to increase the average modulation depth. Any sudden transient peaks breaking through the compressor at high level were removed by a peak clipper. The suppressed-carrier modulators provided either a single-sideband or a double-sideband signal output at a nominal carrier frequency of 1 MHz. A carrier component, correctly phased, was added to the output and adjusted in level to give a maximum modulation depth of 80%. A thumb switch, operated by the listener, allowed an immediate change from one system to the other.

Simulation of selective fading was obtained by heterodyning the modulation r.f. carrier with the outputs from five independent crystal oscillators (100 kHz) in five separate balanced mixers. The feed to four of these mixers was delayed (by either 0·5 ms or 1·0 ms) by means of a switchable r.f. delay line. It has been shown[9] that the sum of four independent oscillators, each of equal amplitude but of randomly varying phase, approximates to a Rayleigh distribution of resultant amplitude. This distribution, together with an appropriate delay, provides a realistic simulation of a sky-wave which, when combined with a steady ground-wave, produces a controllable degree of selective fading. In the apparatus the random phase relationship was obtained by the small uncorrelated drifts in frequency of the crystal oscillators. The overall fading rate was controlled by adjusting the frequency of the fifth oscillator, associated with the ground-wave signal, with respect to the sky-wave oscillators. Depth of fading was adjusted by varying the median value of the sky-wave signal amplitude relative to that of the ground-wave. A bandpass filter centred on 1·1 MHz was used to attenuate mixer products other than the sum of input frequencies.

5.3.2. Test procedure

The operator, after selecting the required transmission parameters and the mode of demodulation in the receiver, asked the listener to rate the grade of reception first with a non-fading signal (i.e. with the sky-wave signal switched off) and then with the simulated fading signal, the

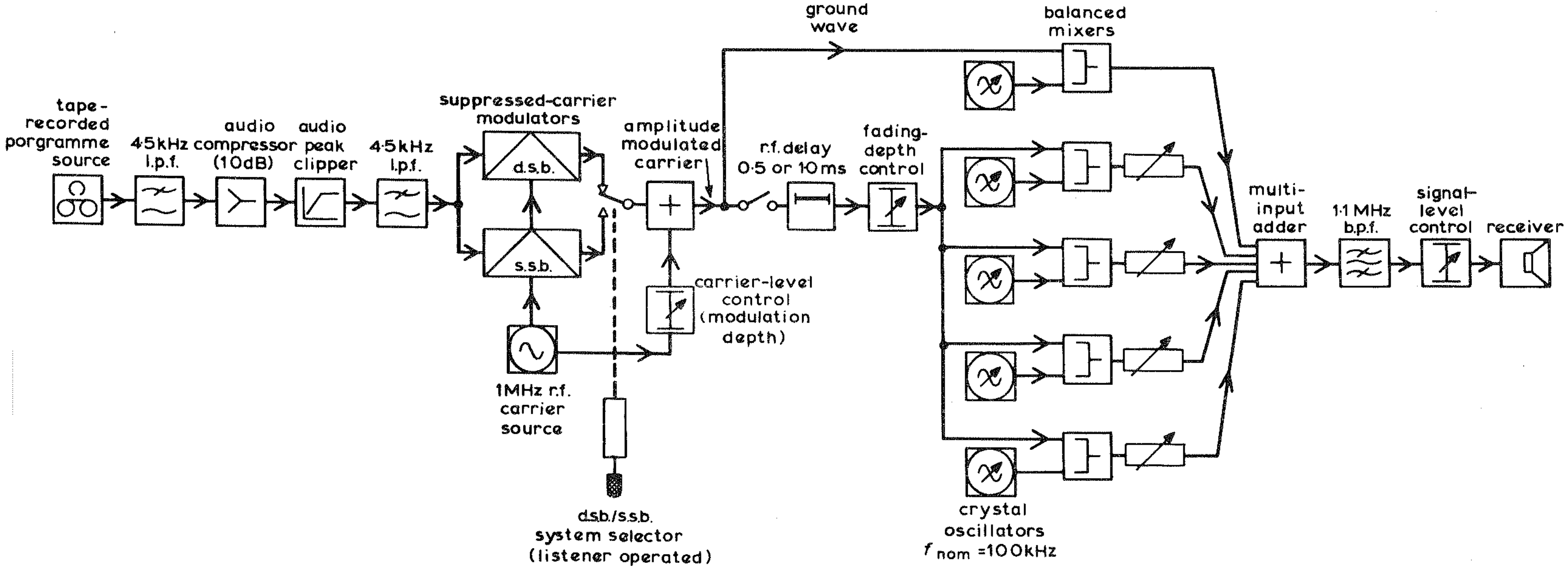


Fig. 4 - Arrangement used for generating fading signals and assessing receiver performance

programme being replayed for each condition. The listener could switch between systems of modulation (each at the same modulation depth) as often as he felt necessary to make an independent quality assessment for each system, labelled (anonymously) A and B respectively.

For the fading-signal tests, the rate of fading was adjusted so that a quasi maximum interference condition occurred at least three or four times during the test-programme listening period (about 8 mins.). As with the home-listening tests, the quality of reception was scored according to the EBU six-point quality scale (see Section 5.2.).

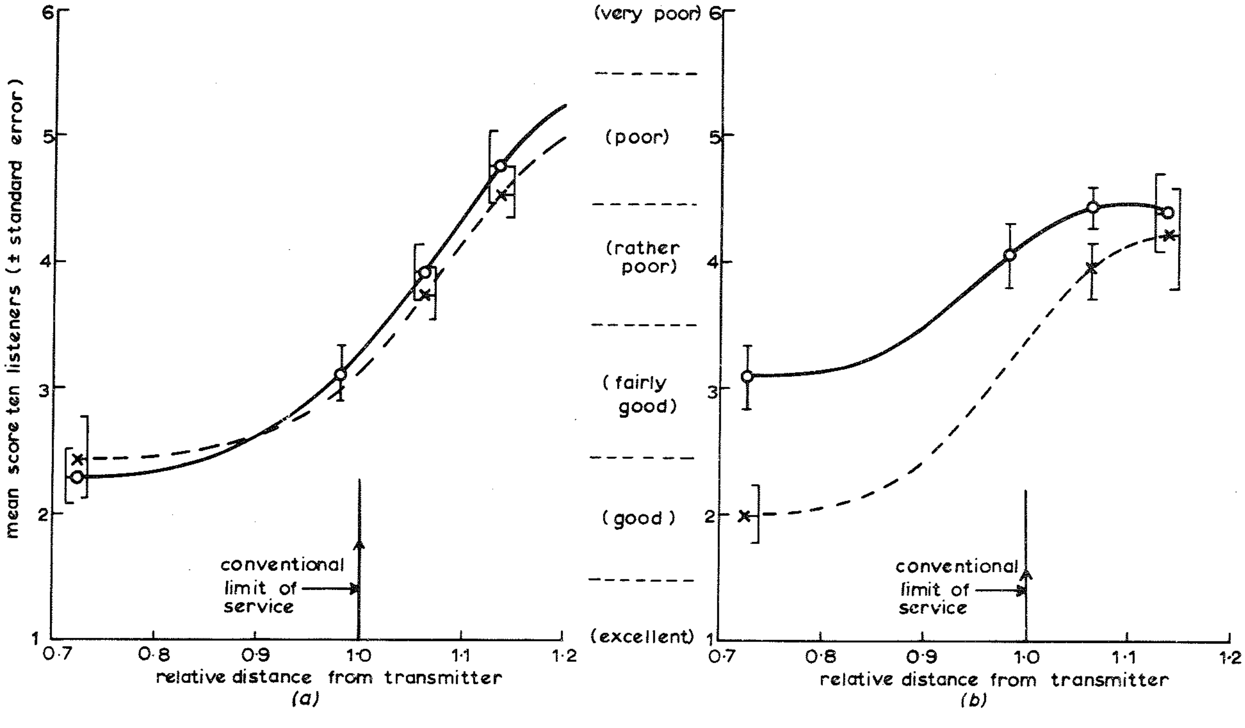
In all cases, the strength of the ground-wave signal alone was such that receiver noise was just perceptible, and was unlikely to affect the judgements made.

5.3.3. Results

For the most part, the system parameters, including a delay time for the sky-wave of 0·5 ms, were adjusted to simulate conditions just beyond the limit of primary service of a typical m.f. transmitter after dark. One set of measurements were made with a 1 ms sky-wave delay and these particular results may be more relevant to the selective fading associated with reception late at night (e.g. with F layer reflections) or with mutual interference between two or more transmitters belonging to a synchronised group.

A summary of the results is shown by the two plots in Figs. 5(*a*) and 5(*b*), where the average grade of reception is indicated as a function of the estimated relative distance from the transmitter. The ordinate value of each plot point is the mean score obtained for ten listeners, for a particular ratio of sky-wave to ground-wave strength. The vertical arrows through the plot points are the standard-error limits of the mean score. The abscissae values, in terms of the relative distance from the transmitter, were derived by equating the ratios of sky-wave to ground-wave field strength used in the tests to those calculated for idealised propagation at medium frequencies. The latter calculation assumed a single reflecting layer at a height of 100 km, a λ/2 base-fed transmitting aerial and uniform ground of average conductivity. In m.f. prediction, the conventional limit of the primary service at night is taken to be the distance at which the calculated sky-wave and ground-wave field strengths are equal, assuming a perfect reflector in place of the ionosphere. At this limit, shown as unit relative distance in Fig. 5, the ratio of actual median sky-wave field strength to the ground-wave field strength is about −6 dB well after sunset. The ratios used in the simulation tests were −5·5, −7·5 and −9·5 dB and the delay times of the sky-wave were 0·5, 0·5 and 1·0 ms respectively. The plot points are linked by dashed-lines (estimated interpolation); it was assumed that for short distances from the transmitter the curves would asymptote in the manner shown to the mean scores obtained in the absence of the interfering sky-wave.

From Fig. 5(*a*), which refers to double-sideband transmissions, it will be seen that, moving into the selective-fading region, the grade of reception deteriorates quite rapidly into the rather-poor/poor categories irrespective of the mode of demodulation. In the fading region, although synchronous demodulation was judged to give the better reception, as expected, the improvement obtained was disappointingly small, and barely significant statistically.



(*a*) (*b*)

Fig. 5 - Results of laboratory tests with simulated selective fading

(*a*) Double-sideband transmission (*b*) Single-sideband (plus carrier) transmission

—o——o— Envelope demodulator
--x---x-- Synchronous demodulator } brackets denote standard errors

Even allowing for the initial difference in the gradings, i.e. under non-fading conditions, and for the statistical error of the mean score, the results suggest that the maximum improvement likely to be obtained in the fading region is about 0·5 grade. Expressed in terms of the night-time coverage zone of a transmitter, any increase would be unlikely to exceed approximately 5% in radius, or 10% in area coverage.

The results for single-sideband plus carrier transmissions (80% maximum modulation depth) show more significant differences. The effect of the inherent increase in the non-linear distortion of the carrier envelope under non-fading conditions is evident. (just over one grade). This difference in the quality of reception between the two modes of demodulation persists well into the selective-fading region but becomes less marked.

There is an indication (c.f. Figs. 5(*a*) and 5(*b*)) that, under severe selective-fading conditions and with larger relative delays between the interfering components, some improvement in the grade of reception is obtained due to the transmission of a single-sideband rather than a double-sideband signal, for either mode of demodulation.

6. Remarks and conclusions

The design problems associated with synchronous demodulation in a domestic radio receiver are formidable, especially if the simplicity, size and low cost of present-day transistor portable receivers are to be approached. Although theoretically an ideal method of demodulation for this application, the increased circuit complexity required to implement it satisfactorily has so far prevented its general use. It can be argued that complexity itself should not bar its eventual introduction, bearing in mind modern developments in integrated circuitry. In the attempts to incorporate synchronous demodulation reported here, however, it was found difficult to avoid a substantial increase in power consumption and in component cost; although economy in these respects was not made the prime objective in the design, such an increase appears to be inevitable.

The most promising approach seems to be that based on isolating the incoming (intermediate) carrier component from its modulation sidebands and using this directly as the synchronous carrier source to affect demodulation. Inherent in this method is a minimum carrier threshold below which the demodulator fails, somewhat abruptly. Some form of automatic frequency control is required in the receiver and, although this might be regarded as a beneficial feature, it does exclude the possibility of deliberately tuning away from an adjacent-channel station to minimise the interference. Moreover, slow-acting a.f.c. makes manual tuning rather tedious and sometimes difficult.

Another unpleasant feature associated with synchronous demodulation is the noisy side-whistle effects that occur during manual tuning. Some form of muting circuit could be used until the carrier has been properly locked in frequency but, if this were effective, it would become extremely difficult to select the required station.

The results of subjective tests with an experimental receiver showed that reception with synchronous demodulation was generally better than with envelope demodulation, but by a disappointingly small margin. For instance, it is estimated that where fading effects limit the effective the primary (ground-wave) service range of a m.f. transmitter radiating d.s.b. signals at night, the area coverage would, at best, be increased by 10%. Predominantly sky-wave reception of more distant stations is improved by synchronous demodulation; the home-listening tests indicated an improvement of approximately 0·75 of a grade. However, this order of improvement is barely sufficient to lift the average grade of reception out of the 'rather poor' category. The limited improvement is largely due to the fact that synchronous demodulation does nothing to alleviate linear (spectral) distortion; this is a factor which should not be under-estimated in entertainment broadcasting. In the latter context, it was found that some improvement in reception derives from the use of single-sideband transmissions when the selective fading is severe, with either mode of demodulation but, near the limit of ground-wave service, s.s.b. appeared to confer no benefit.

The laboratory experiments suggest that the subjective improvement of a simultaneous change of the transmission system from d.s.b. to s.s.b. and of the detection method from envelope to synchronous is little different, overall, from that conferred by a change to synchronous detection with d.s.b. transmissions throughout.

7. References

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